Western North Pacific Tropical Cyclone Formation and Structure Change in TCS08 and TCS08 Field Experiment Support

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Award No: N0001408WR20101

LONG-TERM GOALS

The long-term goal of this project is to develop a better understanding of storm-scale processes in the western North Pacific associated with the entire life cycle of tropical cyclones. The inability to correctly identify tropical cyclone formation over the period of 24 h – 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, the predictability of structure changes during intensification of tropical cyclones is very low. During the intensification stage of a tropical cyclone, structure and track characteristics can exhibit large variabilities that decrease potential predictability. Periods of reduced predictability often occur during the decaying stage of a tropical cyclone. Because decaying tropical cyclones often transitions to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns.

OBJECTIVES

The formation of a tropical cyclone over the western North Pacific often exhibits large fluctuations in timing, rate, and structure. During the initial intensification period, the evolution of the outer wind structure is an important mechanism in driving extreme ocean wave heights. Based on these limitations that impact the ability to predict tropical cyclone formation, intensification, and extratropical transition or decay, there are four primary science objectives:

(i) Identify the role of large-scale influences on the atmospheric mesoscale processes prior to tropical cyclone formation;
(ii) Identify the mesoscale influences on tropical cyclone formation:
(iii) Identify the impacts of fluctuations in tropical cyclone intensity that may be related to factors such as secondary eyewall formation on the variation in outer wind structure evolution and predictability of the overall tropical cyclone track.
(iv) Identify the mechanisms that govern the variability in structural changes associated with the extratropical transition of a tropical cyclone.

Primary objectives relate to the predictability associated with the entire tropical cyclone life cycle that begins with tropical cyclone formation, proceeds through intensification, and concludes with

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE
Western North Pacific Tropical Cyclone Formation And Structure Change InTCS08 And TCS08 Field Experiment Support

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School,Department of Meteorology,Monterey,CA,93943-5114

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
The long-term goal of this project is to develop a better understanding of storm-scale processes in the western North Pacific associated with the entire life cycle of tropical cyclones. The inability to correctly identify tropical cyclone formation over the period of 24 h ? 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, the predictability of structure changes during intensification of tropical cyclones is very low. During the intensification stage of a tropical cyclone, structure and track characteristics can exhibit large variabilities that decrease potential predictability. Periods of reduced predictability often occur during the decaying stage of a tropical cyclone. Because decaying tropical cyclones often transitions to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

extratropical transition unless there is decay over land. For example, the outer wind structure of the tropical cyclone is an important forecast requirement for the Navy because the Fleet afloat must stay outside the 35-knot wind radius, and sorties from port and other base preparations must be completed before gale-force winds make such activities hazardous. Historical reconnaissance data from western North Pacific tropical cyclones demonstrate that outer wind speed increases may occur while the inner wind speed (intensity) remains nearly constant. Conversely, the intensity may increase rapidly with no change in the outer winds. Therefore, objectives are designed to examine the mechanisms responsible for the type of variability defined above.

APPROACH

Operational global model forecasts of tropical cyclone formation are routinely available. However, the objective determination of skill associated with these forecasts for various lead times, locations, and environmental conditions are restricted due to the difficulty in identifying candidate tropical circulation systems that may become tropical cyclones. Therefore, forecasts of tropical vortices made by the National Centers for Environmental Prediction Global Forecast System (GFS), the United States Navy Operational Global Atmospheric Prediction System (NOGAPS), and the United Kingdom Meteorological Office Global Model (UKMO) are analyzed with respect to physical quantities that are relevant to tropical cyclone formation. This approach provides for a feature-based objective analysis of candidate tropical systems. While summarizing statistics such as false alarm rates and probability of detection are readily identifiable from the database, the potential for correct forecasts of tropical cyclone formation in each model is assessed. A comprehensive database of analyzed and forecast values of physically-relevant parameters associated with tropical cyclone formation continues to be updated. This type of analysis is made possible by the objective identification and catalog of model parameters relevant to each tropical vortex.

The primary assumption in applying global model forecasts is that tropical cyclone formation is determined by large-scale environment dynamical conditions, e.g., a cyclonic vorticity in the lower troposphere and minimum vertical wind shear, and presuming that the thermodynamic conditions of a SST > 26°C and moist mid-troposphere conditions also exist. The alternate hypothesis is that the location, timing, and physical processes determining TC formation are related to the locations, amplitudes, and evolutions of the mesoscale convective systems (MCSs) in those favorable large-scale environmental conditions.

Two primary hypotheses have been advanced for the role of the MCSs and their associated mesoscale convective vortices (MCVs) in tropical cyclone formation. The “top-down hypothesis” is that only the MCS/MCV that forms in the middle of a monsoon depression, where minimum vertical wind shear and a warm, moist, cyclonic vorticity environment exists, is able to become the point about which the central convection is concentrated to form the tropical cyclone. Once the region of central convection has been established, the vortex is able to organize via mechanisms associated with the strong updrafts that induce a secondary circulation that increases the tangential winds.

The key elements of the “bottom-up hypothesis” are that strong, deep convection in a favorable cyclonic vorticity environment creates multiple lower-tropospheric cyclonic vortices that merge to create a progressively more intense vortex that builds upward. The latent heat release in this intense vortex leads to a secondary circulation that can spin-up the vortex into a warm-core tropical cyclone with maximum winds in the lower troposphere.

The key to understanding the physical processes by which a MCS/MCV can form a tropical cyclone is to observe and model the horizontal and vertical distribution of latent heating. That is, the vertical distribution of latent heating associated with both the convective portion and stratiform portions of the MCS is a critical component. The combined observation-modeling approach is to be followed based on observations from the Tropical Cyclone Structure-08 (TCS-08) field program and collaboration with scientists at the Naval Research Laboratory and the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS).

The primary examination of tropical cyclone structure change during intensification is based on the examination of the relative impact of the structure at the time of formation versus environmental and storm-scale processes that evolve during the life-cycle of the tropical cyclone. Structural characteristics at the time of formation are defined as monsoon, wave, or tropical upper-tropospheric trough (TUTT) types. Following formation, internal and external factors may act to alter the structural characteristics of the intensifying tropical cyclone.

The poleward movement and extratropical transition (ET) of a tropical cyclone initiates complex structural changes in the wind distribution and ocean forcing. Furthermore interactions with the midlatitude environment that often results in a high-impact midlatitude weather system with strong winds, high seas, and large amounts of precipitation. Although these extreme conditions severely impact the region of the ET, there are significant impacts downstream of the ET event due to the excitation of large-scale propagating Rossby wave-like disturbances. The approach to the primary scientific issues associated with ET and downstream impacts due to ET events is to define a framework of mechanisms, predictability, and strategies for increasing predictability. The approach is to investigate the roles of environmental factors during ET on structural changes responsible for the generation, intensification, and propagation of Rossby wave-like disturbances that often form during ET events.

WORK COMPLETED

A framework for diagnostic analysis of forecasts of tropical cyclone formation from operational global models was defined and implemented. Diagnostic analyses of several cases of the ET of tropical cyclones over the western North Pacific were completed to identify structural changes and relative roles of large-scale environmental factors. In preparation for the TCS-08 field program, a dry-run experiment period was analyzed to define observation strategies, operational constraints, and logistical procedures by which the actual program could be based.

Overall logistical and operational support was accomplished prior and during the field phase of TCS-08. This included operations management, mission planning, and participation in the field by graduate students. Additionally, several workshops/meetings were convened to develop a science and operations plan for TCS-08

RESULTS

The examination of the ET of Super Typhoon Man-yi (04W) in the western North Pacific identified relative roles of the lower-level diabatic and upper-level dynamic processes as mechanisms associated with structural changes and impacts to the large-scale environment (Sanabia and Harr 2008). Although

the ET of Man-yi was not related to favorable phasing of the TC and an upstream synoptic-scale trough, the ET did result in a strong extratropical cyclone and high-amplitude downstream wave pattern across the entire North Pacific. Although warm-air advection and related diabatic processes were present, they were not the primary mechanisms that led to amplification of the downstream longwave pattern. Instead, the outflow of the transitioning TC provided the kinetic energy necessary for downstream development. This upper-level dynamic process deepened the adjacent trough and passed kinetic energy downstream which amplified the longwave pattern.

A spectrum of ET characteristics and impacts on the large-scale environment was examined by Harr and Dea (2008). The relative roles of these physical characteristics associated with structural changes are investigated with respect to their impact on overall variability in the impact on the large-scale atmosphere/ocean environment along the path of the tropical cyclone as it undergoes ET. The ET of tropical cyclones has a major impact on the distribution of eddy kinetic energy over the entire North Pacific basin.

The implementation of the TCS-08 field program resulted in several "firsts" with respect to tropical cyclone observations over the western North Pacific. These included the first deployment of a set of drifting buoys directly in the path of a super typhoon; coordination of aircraft missions and eye penetrations with the overpasses of polar-orbiting satellites, observations by four aircraft simultaneously in one typhoon, aircraft missions throughout the entire life cycle of a tropical cyclone, and a systematic application of the use of targeted observations for improving tropical cyclone track forecasts.

IMPACT/APPLICATIONS

The TCS-08 field program has provided a unique data set that describes the life cycle of tropical cyclones over the western North Pacific. The comprehensive data set will provide for a wide variety of opportunities for numerical and diagnostic studies of tropical cyclone characteristics plus validation of theories. The overall impact of this research will be measured in increased accuracy associated with the prediction of tropical cyclone formation, intensification, and structural changes.

TRANSITIONS

Following the compilation and analysis of the wide range of TCS-08 data sets, research results that identify factors responsible for the variability in tropical cyclone formation, intensification, and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific.

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